BONN-HE-2000-01
June 2000

# LEPTON FLAVOUR VIOLATION AT HERA

R. KERGER[a]
(on behalf of the ZEUS and H1 collaborations)
*Physikalisches Institut der Universität Bonn, Nußallee 12, D-53115 Bonn, Germany*
*E-mail: kerger@physik.uni-bonn.de*

The $e^+p$-data collected with the ZEUS ($\mathcal{L} = 47.7\,\mathrm{pb}^{-1}$) and the H1 ($\mathcal{L} = 37\,\mathrm{pb}^{-1}$) detectors at HERA in 1994–1997 are analysed for signals of lepton flavour violation mediated by leptoquark exchange, both in the muon and the tau channels. No evidence for lepton flavour violation is found and limits on the leptoquarks' Yukawa couplings are set.

## 1 Introduction

Within the standard model (SM) all interactions conserve lepton flavour individually, allowing us to assign the leptons to three distinct generations. It is, however, not clear if lepton flavour is a fundamental quantum number since it has not yet been brought into relation with an underlying symmetry. Many extensions of the SM therefore contain lepton flavour violation. Recently, Super-Kamiokande [1] has reported evidence for oscillation of atmospheric neutrinos. This is the first experimental observation of lepton flavour violation (LFV).
At HERA, LFV could occur in $eq_1 \to \ell q_2$ scattering, the typical signature being an isolated higher-generation lepton ($\ell = \mu, \tau$) instead of the scattered electron. This process could be mediated by leptoquarks with mass $M_{LQ}$, which allow couplings both to $(eq_1)$ and to $(\ell q_2)$ pairs. If $M_{LQ} < \sqrt{s}$ ($\sqrt{s} \approx 300\,\mathrm{GeV}$ being the HERA centre-of-mass energy), LQs are predominantly produced in the $s$-channel. In this case, using the narrow-width approximation (NWA), the resonant production cross section, $\sigma_{\mathrm{NWA}}$, is proportional to $\lambda^2_{eq_1} \times \mathrm{BR}_{\ell q_2} \times q(x = \frac{M^2_{LQ}}{s})$, $\lambda_{eq_1}$ being the Yukawa coupling at the LQ production vertex, $\mathrm{BR}_{\ell q_2}$ the branching ratio for the decay $LQ \to \ell q_2$ and $q$ the quark density. If $M_{LQ} \gg \sqrt{s}$, both the $s$- and $u$-channels contribute to the cross section. Since the propagator contracts to an effective four-fermion interaction, the cross section is proportional to $\left[\frac{\lambda_{eq_1}\lambda_{\ell q_2}}{M^2_{LQ}}\right]^2 \equiv [\Psi^\ell_{q_1 q_2}]^2$.

## 2 Analysis and Results

### *2.1* $e \leftrightarrow \mu$

The main signature consists of a high-transverse-momentum muon together with a jet and the absence of an isolated electron. After the preselection, H1

[a]Supported by a grant from the German "Bundesministerium für Bildung und Forschung".

finds 4 ($\mu$+jet)-events, compared to the SM-expectation of $0.6 \pm 0.1$ events. These events [2] are, however, not consistent [3] with a final state as expected for LQ processes and are removed by the final selection cuts (requiring among other things $\mu$ and the hadronic final state to be back to back in azimuth). Both H1 and ZEUS finally observe no candidate.

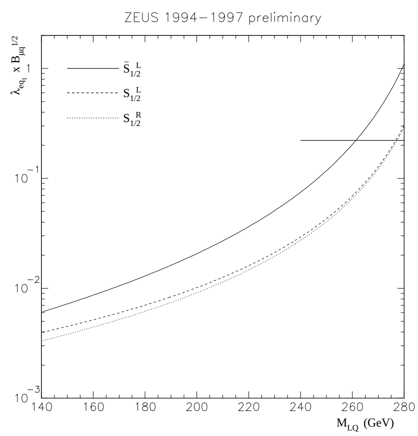


Figure 1: 95 % CL upper limit on $\lambda_{eq_1} \times \sqrt{\mathrm{BR}_{\mu q_2}}$ for scalar leptoquarks with fermion number F=0. $\tilde{S}^L_{1/2}$ couple to $d$-quarks only, $S^L_{1/2}$ couple to $u$-quarks only and $S^R_{1/2}$ couple to both $u$- and $d$-quarks.

Figure 1 [4] displays the limits on $\lambda_{eq_1} \times \sqrt{\mathrm{BR}_{\mu q_2}}$ for different resonantly produced F=0 scalar leptoquarks as a function of the LQ mass; the areas above the lines are excluded at 95% confidence level (CL). If electromagnetic coupling strength $\lambda_{eq_1} = \sqrt{4\pi\alpha}$ and $\mathrm{BR}_{\mu q_2}$=0.5 are assumed (as indicated by the horizontal bar in Fig. 1), masses of leptoquarks up to 260 – 280 GeV, depending on the LQ type, are excluded. This complements the results obtained by the TeVatron experiments [5] which exclude flavour-diagonal LQs decaying only into $\mu + q$ up to masses of 200 GeV.

## *2.2* $e \leftrightarrow \tau$

The searches in the $\tau$-channel have to use the final-state properties of the $\tau$ since its decay vertex cannot be resolved. Hadronic $\tau$ decays are identified by requiring a narrow collimated jet with 1 to 3 reconstructed tracks. Furthermore, events of that kind are required to have a net transverse momentum aligned in azimuth with the narrow jet associated with the hadronic $\tau$ decay products. Leptonic $\tau$ decays are identified by requiring, in addition to a large missing $p_t$, a high-$p_t$ charged lepton in the missing-$p_t$ direction. ZEUS takes all decay modes into account; H1 considers the hadronic decays separately – the muonic $\tau$ decays are covered by the $e \leftrightarrow \mu$ analysis, whereas the $\tau \to e\nu\bar{\nu}$ decays are not used. No event survives the selection. For several vector LQs, Fig. 2 displays the mass-dependent upper limits on $\lambda_{eq_1} \times \sqrt{\mathrm{BR}_{\tau q_2}}$. By assuming a Yukawa coupling of electromagnetic strength (as indicated by the horizontal bar in the plot) and $\mathrm{BR}_{\tau q_2} = 0.5$, LFV LQs with masses smaller than 265–285 GeV, depending on the type, can be excluded.

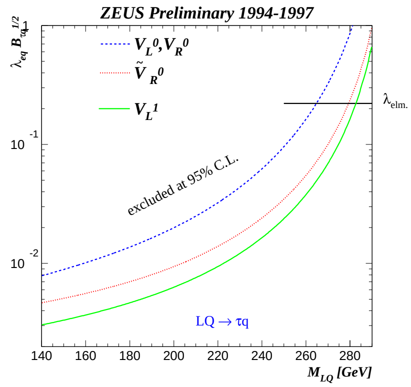


Figure 2: 95% CL ZEUS upper limits on $\lambda_{eq_1} \times \sqrt{\mathrm{BR}_{\tau q_2}}$ for F=0 vector LQ as a function of LQ mass.

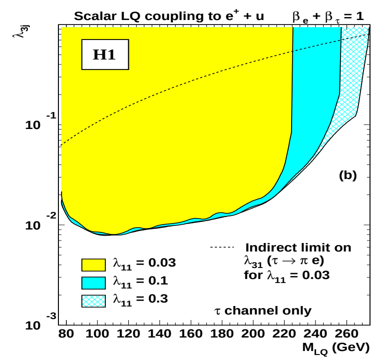


Figure 3: Mass-dependent H1 limits on $\lambda_{\tau q_2}$ for a scalar LQ coupling to $e^+ + u$, for different values of $\lambda_{eq_1}$

Figure 3 [3] shows mass-dependent limits on $\lambda_{\tau q_2}$ for $S^L_{1/2}$ LQs for several values of $\lambda_{eq_1}$. As can be seen, HERA has a substantial sensitivity on $\lambda_{\tau q_2}$ for LQs which are light enough to be resonantly produced via $\lambda_{eq_1}$. These LQs are assumed to couple only to $eq$ and $\tau q$ ($\mathrm{BR}_{eq_1} + \mathrm{BR}_{\tau q_2} = 1$). If both $\lambda_{eq_1}$ and $\lambda_{\tau q_2}$ are of electromagnetic strength, HERA excludes such scalar LQs up to 270 GeV. The TeVatron collider experiments complementarily exclude third generation LQs (coupling to third generation fermions only) up to 99 GeV [6] (94 GeV [7]) for $\mathrm{BR}_{\tau b} = 1$ ($\mathrm{BR}_{\nu b} = 1$).

For all F=0 LQs with masses $M_{LQ} \gg \sqrt{s}$, limits on $\Psi^{\tau}_{q_1 q_2}$ are shown in Table 1. The HERA limits are compared to the most stringent indirect limits [3]. The superscript on the HERA limits indicates whether the strongest HERA limit comes from ZEUS (Z) or from H1 (H) [3]. Although ZEUS has a higher integrated luminosity and considers both the leptonic and hadronic decay modes of the $\tau$, there are several cases where H1 reports stronger limits. This is due to the fact that H1 assumes a common selection efficiency for all quark combinations whereas ZEUS evaluates the efficiencies for each possible $q_i q_j$-combination individually. The ZEUS and H1 limits are stronger (bold numbers in Tab. 1) than those from low-energy measurements in several slots, especially if higher generation quarks are involved. ZEUS and H1 also set limits for some hitherto unconstrained flavour combinations.

## 3 Conclusions

No evidence for LFV was found in the ZEUS and H1 1994-1997 $e^+p$ data. Exclusion limits on $\lambda_{eq_1} \times \sqrt{\mathrm{BR}_{\ell q_2}}$, $\lambda_{\tau q_2}$ and on $\frac{\lambda_{eq_i}\lambda_{\ell q_j}}{M^2_{LQ}}$ have been set. Assuming

| $q_iq_j$ | $S^L_{1/2}$ | $S^R_{1/2}$ | $\tilde{S}^L_{1/2}$ | $V^L_0$ | $V^R_0$ | $\tilde{V}^R_0$ | $V^L_1$ |
|---|---|---|---|---|---|---|---|
| 1 1 | $0.030^Z$ <br> $0.0032^a$ | $0.025^Z$ <br> $0.0016^a$ | $0.046^Z$ <br> $0.0032^a$ | $0.033^Z$ <br> $0.002^b$ | $0.033^Z$ <br> $0.0016^a$ | $0.024^Z$ <br> $0.0016^a$ | $0.012^Z$ <br> $0.002^b$ |
| 1 2 | $\mathbf{0.030}^Z$ | $\mathbf{0.025}^Z$ <br> $0.05^c$ | $\mathbf{0.046}^Z$ <br> $0.05^c$ | $0.036^Z$ <br> $0.03^c$ | $0.036^Z$ <br> $0.03^c$ | $\mathbf{0.026}^Z$ | $0.012^Z$ <br> $2.5 \cdot 10^{-6\ d}$ |
| 1 3 | * | $\mathbf{0.049}^Z$ <br> $0.08^e$ | $\mathbf{0.049}^Z$ <br> $0.08^e$ | $0.044^Z$ <br> $0.02^f$ | $0.044^Z$ <br> $0.04^e$ | * | $0.044^Z$ <br> $0.02^f$ |
| 2 1 | $\mathbf{0.15}^H$ | $0.092^Z$ <br> $0.05^c$ | $0.105^Z$ <br> $0.05^c$ | $0.049^Z$ <br> $0.03^c$ | $0.049^Z$ <br> $0.03^c$ | $\mathbf{0.061}^Z$ | $0.026^Z$ <br> $2.5 \cdot 10^{-6\ d}$ |
| 2 2 | $0.18^H$ <br> $0.03^g$ | $0.10^H$ <br> $0.02^g$ | $\mathbf{0.120}^Z$ | $\mathbf{0.061}^Z$ | $\mathbf{0.061}^Z$ | $\mathbf{0.102}^Z$ | $\mathbf{0.041}^Z$ |
| 2 3 | * | $0.14^H$ <br> $0.08^e$ | $0.14^H$ <br> $0.08^e$ | $0.102^Z$ <br> $0.02^f$ | $0.102^Z$ <br> $0.04^e$ | * | $0.102^Z$ <br> $0.02^f$ |
| 3 1 | * | $0.16^H$ <br> $0.08^e$ | $0.16^H$ <br> $0.08^e$ | $0.052^Z$ <br> $0.002^h$ | $0.052^Z$ <br> $0.04^e$ | * | $0.052^Z$ <br> $0.002^h$ |
| 3 2 | * | $0.19^H$ <br> $0.08^e$ | $0.19^H$ <br> $0.08^e$ | $0.073^Z$ <br> $0.02^f$ | $0.073^Z$ <br> $0.04^e$ | * | $0.073^Z$ <br> $0.02^f$ |
| 3 3 | * | $\mathbf{0.23}^H$ | $\mathbf{0.23}^H$ | $\mathbf{0.14}^H$ <br> $0.51^g$ | $\mathbf{0.14}^H$ <br> $0.51^g$ | * | $\mathbf{0.14}^H$ <br> * |

Table 1: 95 % CL limits on $\Psi^{\tau}_{q_1 q_2}$ (in $10^{-4}\,\mathrm{GeV}^{-2}$) for F=0 leptoquarks. The first line in each row shows the best HERA limits; the superscripts Z and H indicate ZEUS or H1 results, respectively. The numbers in bold characters indicate the cases where HERA provides the strongest limits. The second line in each row states the most stringent low-energy constraint. The superscripts indicate the respective low-energy measurement: (a) $\tau \to \pi e$, (b) $G_F$, (c) $\tau \to Ke$, (d) $K \to \pi\nu\bar{\nu}$, (e) $B \to \tau e X$, (f) $B \to l\nu X$, (g) $\tau \to e\gamma$, (h) $V_{ub}$. The * indicates the cases which would involve a top quark.

electromagnetic coupling strength, resonantly produced LFV LQs with masses up to 260–285 GeV are excluded. For LFV LQs with $M_{LQ} \gg \sqrt{s}$, H1 and ZEUS set limits for hitherto unconstrained flavour combinations and improve several existing limits, especially for $e \leftrightarrow \tau$ transitions.

## References


1. Y. Fukuda et al., Super-Kamiokande Collaboration, *Phys. Rev. Lett.* **81**, 1562 (1998)
2. C. Adloff et al., H1 Collaboration, *Eur. Phys. J.* C **5**, 575 (1998)
3. C. Adloff et al., H1 Collaboration, *Eur. Phys. J.* C **11**, 447 (1999)
4. ZEUS Collaboration, Abstract 551, EPS99, Tampere, July 1999
5. B. Abbott et al., D0 Collaboration, *Phys. Rev. Lett.* **84**, 2088 (2000)
6. F. Abe et al., CDF Collaboration, *Phys. Rev. Lett.* **78**, 2906 (1997)
7. B. Abbott et al., D0 Collaboration, *Phys. Rev. Lett.* **81**, 38 (1998)